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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: February 11, 1974

Project Title: "Study and Evaluation of Buried Dipole Antennas"

Project No.: A-1593

Project Director: Mr. H. H. Jenkins

Sponsor: U.S. Army Electronics Command; Fort Monmouth, New Jersey

Effective January 1, 1974 Estimated to run until December 31, 1974 (Work Period)

Type Agreement: Contract No. DAAB07-74-C-0103 Amount: $ 71,958.00

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Secret

DEFENSE PRIORITY RATING: DO-A7 under DMS Reg. 1

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PROJECT TERMINATION

Date: September 25, 1975

Project Title: Study and Evaluation of Buried Dipole Antennas

Project No.: A-1593

Project Director: Mr. H. H. Jenkins

Sponsor: U. S. Army Electronics Command; Fort Monmouth, New Jersey

Effective Termination Date: 5/23/75 (Final Report due - approval 4/23/75)

Clearance of Accounting Charges: 5/31/75

Grant/Contract Closeout Actions Remaining:

Final Invoice & Closing Documents
Final Report of Inventions
Gov't. Property Inventory & Cert.

Assigned to: Communications

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A-1593
Final Classification Restricted

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

30 January 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report No. 1, Project A-1593, "Buried Dipole Antennas," Contract DAAB07-74-C-0103, 1 January to 1 February 1974

Gentlemen:

The research work to be performed under Contract DAAB07-74-C-0103 in accordance with Development Specification DS-EN-0154(A) has been divided into six phases as listed below:

Phase I: Definition of model scaling factor, topology resolution, and modeling materials.

Phase II: Construction of the model; development of the instrumentation and measurement techniques; and verification of the model performance.

Phase III: Investigation of the performance of an added East-West antenna using the model; recommend placement and orientation based on radiation pattern measurements.

Phase IV: Determination of buried antenna efficiency vs. burial depth using approximate 20:1 scale model antenna implanted in the earth.

Phase V: Field strength calculations at Sites B and C.

Phase VI: Preparation of final report.

During January, work in Phases I and II began.

Initial Efforts on Program

On January 9-10, 1974, a post-contract award meeting was held at the U.S. Army Electronics Command. Participants included Georgia Tech project personnel, the cognizant USAECOM Contracting Officers' Technical Representative, and representatives from DCA, USACSA, USACC, and USACEEA.

At this meeting an immediate need for some basic information concerning the effects of buried antenna placement on radiation characteristics was expressed, and it was decided that the initial contract effort should be on this requirement. A large majority of the work in January has been devoted to this effort which is described below.

The basic objective is to determine the effects of antenna tilt in the elevation plane and local topology (mountains) on the radiation pattern via use of modeling techniques. Present plans are to use a scale factor of approximately 7 x 10^3 and construct a relatively simple, flat, scaled-ground model in a 3.6m x 3.6m x 5.4m anechoic chamber. A scaled model of a North-South dipole will be placed on the ground model and its radiation pattern measured as a function of element tilt angle in the elevation plane. The effects of nearby uneven ground topology (simulating mountains) on the radiation pattern will be determined by introducing appropriately scaled irregularities on the scaled-earth model.

The earth model will have a diameter of 3m or 4.1 λ at the scaled operating frequency of 410.9 MHz. Radiation patterns will be measured using a transmitting source some 2 λ from the scaled buried antenna, which will have a total length of 12 cm. Present plans are to produce a model material with a conductivity of approximately 0.7 mhos/m based on a postulated Site A earth conductivity of 10^{-4} mhos/m. The properties of various mixtures of 340 mesh sand and graphite and 350 mesh sand and carbon black are currently being experimentally investigated in order to obtain an appropriate material.

All of the instrumentation required for the model pattern measurements has been assembled and checked out. The instrumentation consists of (1) a Scientific/Atlanta positioner which will be used to rotate the scaled-earth model about a vertical axis, (2) an NF-105 field intensity meter, (3) a Scientific/Atlanta pattern recorder, and (4) a signal source obtained by using a HP608 generator feeding a balanced dipole.

The integrity of the anechoic chamber in the frequency range from 400 to 500 MHz has been verified by measuring the antenna response patterns of a standard gain horizontal dipole, the scaled-model dipole antenna, and a vertical monopole. The patterns indicate that virtually "free-space" conditions exist in the chamber.

A major task of the initial effort will be to demonstrate that the "conventional" azimuth radiation pattern of a buried horizontal dipole can be duplicated using the scaled-earth model and scaled buried antenna. We will be looking for a pattern with maximum response along the axis of the buried horizontal dipole and minimum broadside response. If a pattern with these characteristics can be obtained, the existence of the appropriate slow traveling wave antenna coupling mechanism and the resultant Norton surface wave is implied. It should be stressed that the attainment of the appropriate pattern is a major technical milestone and must be accomplished before the scaled model can be considered a legitimate simulation.

Investigation of Model Scale Factor

The scaling factor of 7 x 10^3 cited above was chosen based on a "quick look" analysis and motivated by a need to respond rapidly on the initial effort. The 7 x 10^3 factor may or may not be optimum. The scaling factor must be chosen in order to accommodate (1) reasonable model dimensions and terrain resolution requirements, (2) realizable earth model materials, and (3) practical instrumentation and measurement techniques. An analytical effort is underway which is defining the effects of scale factor on total model dimensions, topographical contouring resolution, and model material implementation. We are considering scale factors from 10^3 to 10^4.

Work During Next Interval

During February, work will continue on the quick-reaction effort with emphasis on producing the appropriate modeling material and experimental investigations of antenna orientation and topological effects using the scaled model.

Respectfully submitted:

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

DWR:iln

A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

28 February 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report No. 2, Project A-1593, "Buried Dipole Antennas", Contract DAAB07-74-C-0103, 1 February to 1 March 1974.

Sir:

The various phases of the program have been defined in Monthly Status Report No. 1. During February significant progress was made on Phase I, Model Definition, and Phase II, Model Construction and Verification.

Phase I, Model Definition

Efforts have concentrated on topology definition and the formulation and preparation of modeling materials.

Topology Definition

The terrain lying within a radius of 2λ (10.2 km) from Site A has been characterized in the frequency domain by converting maximum elevation values to wavelengths at 58.7 kHz. (Site A is located in a mountainous region with ridgelines in a NNE-SSW direction. The average elevation of the valleys to the east and west is about 700 feet). Within a radius of 10.2 km, 102 elevation peaks have been identified and elevation determined with an accuracy of $\pm$ 20' as obtained from a 1:24000 topo map. The elevations were referenced to a mean "valley" elevation of 700 feet. A statistical analysis of the elevation data, normalized to wavelengths, provided a mean elevation of $.048\lambda$ (804') and a standard deviation of $.012\lambda$ (203'). Therefore, the terrain roughness in the elevation plane is approximately $\lambda/20$. In general, it is agreed that a surface is not "rough" unless the irregularities exceed $\pm\ \lambda/16$ from the mean or a total roughness variation of $\lambda/8$. A major implication is that the irregularities of the terrain surrounding Site A are small relative to a wavelength and, hence, may have negligible effect on the far-field radiation pattern.

High Conductivity Modeling Materials

Although the conductivity of the soil near an embedded antenna has some importance, the average conductivity of the earth supporting the antenna ground current is more important. Based on conversations with Mr. W. P. Czerwinski, USAECOM, and Dr. Franklin Moore, DCA, the average ground conductivity to be used in determining the scaled conductivity is 10^{-4} mhos/m. In fact, a 3-layer model suggested by Dr. Howard Pratt, Terratek Corporation, indicates a conductivity of 10^{-4} mhos/m at depths below 2 meters.

Since the dimensions of the terrain antenna are scaled by a factor of 1/8000 for the initial radiation pattern measurements, the conductivity of the terrain must be scaled by a factor of 8000. This then means a model terrain conductivity on the order of 0.8 mhos/m. The complex permittivity of the scaled terrain must be the same as the actual terrain. The relative dielectric constant, ϵ_r, is between 10 and 12 and the value for the loss tangent lies between 0.5 and 0.7 [1, Figure 4].

It is known that a mixture of dry sand and graphite will result in high conductivity media [2,3]. Samples of granulated graphite, Cabot Corporation Vulcan XC-72R carbon black, and Cities Service Conductex 950 SL-3665 carbon black were obtained to mix with 325 mesh silica. Numerous mixing ratios of the silica to one of the conductive materials were tested for dielectric constant, loss tangent, and conductivity. Typical average data are tabulated in Table I. The mixture of 7 parts by volume of the silica to 5 parts of graphite was selected for the initial buried dipole antenna measurements. Approximately 10 cubic feet of material has been mixed and placed on the ground plane.

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[1] Acker M. and L. J. Mueller, "Some Measured Electrical Characteristics of the Earth's Crust," U. S. Army Electronics Command, Communications/ADP Laboratory, Fort Monmouth, New Jersey.

[2] Abul-Kassem, Ahmed, et al., "Experimental Investigation of the Impedance of a Horizontal Linear Antenna Above a Dissipative Homogeneous Earth," 1973 USNC/URSI Meeting, Boulder, Colorado, August 1973.

[3] Winder, D. E., I. R. Pedenand, and H. M. Swarm, "A 3 Gc/s Scale Model of a Submerged VLF Antenna Using Lossy Ceramic Powder," <u>IEEE Transactions on Antennas and Propagation</u>, AP-14, No. 4, July 1966.

A number of important antenna effects can be determined using the test bed as it now stands. These effects include the sloping of the antenna elements, burial depth, and terrain perturbations. Measurements will be made to determine the magnitude of these effects.

From these data, it will then be possible to determine the dimension accuracy required in a final scale model of the local terrain surrounding the antenna at Site A.

Phase II, Model Construction

Model Tests

Late in February, the initial batch of mixed material was placed on the ground plane in the anechoic chamber to form a crude, partial earth model. The scaled dipole antenna was embedded in the material, and the azimuthal response pattern was measured. The existence of an end-fire pattern was observed indicating that the appropriate slow traveling-wave antenna coupling mechanism has been obtained and that a Norton vertically-polarized surface wave has been established. The results imply the validity of the modeling approach and, hence, indicate that a major technical milestone of the project has been attained.

Analysis of NRL Radiation Pattern Data

The Statement of Work requires that the model be authenticated by comparing the radiation characteristics of the model of the existing North-South antenna with previous measurements obtained on the full-scale antenna. Field strength data obtained by the Naval Research Laboratory have been analyzed. These data were obtained at a distance of 10 statute miles using 34 locations distributed 360° in azimuth relative to the antenna at Site A. It is understood that the data were acquired from an aircraft.

A continuous plot of field strength versus azimuth was fitted by NRL to the 34 data points. The major objective of our analysis was to determine the statistical variation of the data points relative to the plotted curve. The analysis showed that the mean variation from the plotted curve was 0dB with a standard deviation of 1.9 dB. Therefore, it appears that the plotted curve has a tolerance variation of $\pm$ 1.9 dB. The major implication is that the approximate 3 dB difference between the North and South radiation levels indicated by the plot may not be statistically significant.

TABLE I

ELECTRICAL PROPERTIES OF SAND*-GRAPHITE AND SAND*-CARBON BLACK MIXTURES

Mixture (By Volume)	Relative Dielectric Constant	Loss Tangent	Conductivity (mhos/m)
Sand-Graphite 1:1	22.0	5.67	0.7
6:5	12.4	2.78	0.36
7:5	11.3	1.73	0.12
8:5	10.5	0.84	0.05
9:5	9.3	0.53	0.03
2:1	9.6	0.57	0.03
3:1	4.5	0.14	0.003
4:1	3.8	0.13	0.003
Sand-Carbon Black (Vulcan) 1:1	4.2	0.194	0.045
2:1	3.7	0.24	0.005
2.5:1	3.6	0.176	0.003
10:3	2.4	0.14	0.018
5:1	2.3	0.158	0.002
10:1	1.9	0.122	0.001
Sand-Carbon Black (Conductex)			
1:1	7.5	0.58	0.02
7:5	4.9	0.28	0.008
2:1	3.6	0.14	0.003
4:1	2.9	0.06	0.001
5:1	3.0	0.14	0.002

* 325 Mesh Silica Powder (Dry)

The dispersion of the individual data points were also analyzed from the viewpoint of local terrain characteristics such as mountains and valleys. No discernible correlation between dispersion and topology is evident.

Parametric Analysis

Key parameters of the existing full scale buried antenna have been calculated for comparison with measured scaled parameters. Calculated values include resonant length and input impedance at resonance. The calculated values have been obtained as functions of burial depth and soil conductivity. Calculations to this point indicate substantial agreement with full scale measured values. For example, with a conductivity of 10^{-3} mhos/meter and a burial depth of 0.46 meters, RG-17 cable with outer shield removed was found to have a resonant length of 902 meters. The computed characteristic impedance for this configuration was found to be 98-j3.6 ohms, and the input resistance at resonance was calculated to be 24.7 ohms. These values were based on the assumption of an ungrounded-end dipole antenna. Analytical expressions suggest that little variation in antenna parameters will occur for shallow burial depths. Calculations for burial depth ranging from 0.5 to 2 meters and conductivity from 10^{-2} to 10^{-4} mhos/meter show less that 25% variation in attenuation and phase constants.

Trips and Conferences

On February 12-13, 1974, H. L. Bassett and H. H. Jenkins visited Site A for an overall view of the installation and surrounding environs. Also, a general review of the project was presented to the cognizant USAECOM Contracting Officers' Technical Representative, and representatives from DCA, USACSA, and USACEEIA.

Work During Next Interval

During March, Preparation of the material for the initial scaled model will be finished and the model completed. Work will then begin on the investigation of antenna orientation and topological effects on the radiation pattern.

Respectfully submitted:

H. H. Jenkins, Project Director

Approved:

D. W. Robertson, Chief
Communications Division

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 April 1974

Mr. W. P. Czerwinski
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United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 3, Project A-1593, "Buried Dipole Antennas," Contract DAAB07-74-C-0103, 1 March to 1 April 1974.

Sir:

During March, significant progress was made on investigating buried dipole effects using the 8000:1 scale model. Summarized below are pertinent parameters of the model.

Scaled Test Frequency: 470 MHz
Diameter: 4.6λ
Scaled Dipole Antenna Length: 10.7 cm
Earth Modeling Material: Graphite and Sand; 7:5
Material Conductivity: 0.12 mhos/m
Material Dielectric Constant: 11.3
Material Loss Tangent: 1.73
Nominal Material Depth: $\sim 1\ \delta$ (one skin depth)

A series of tests have been performed using the model with the major objectives as follows:

1. Verify the model.
2. Define measurement repeatability and data tolerance.
3. Determine the effects of the following factors on the buried antenna radiation characteristics.
   - Orientation of the dipole on the modeled mountain (East-West and North-South).
   - Antenna element droop and inclination angle.
   - Above and below ground operations areas and above ground cabling.
   - Local terrain effects such as an extended mountain ridgeline.

The series of tests have been performed in a sequence of three steps with a progressively more complex model for each series. During the <u>first series</u>, a smooth, level model was used with a nominal material depth of one skin depth and the scaled model dipole. On the <u>second series</u>, rectangular and hexagonal models of the Site A mountain were added to the smooth model and the scaled dipole implanted on the mountain model. On the <u>third series</u>, a scaled mountain range was added and used with the hexagonal Site A model.

The following material summarizes the sequence of tests by presenting the various objectives of each series and the major results for each objective.

Series 1: Level Model Tests (Verification of Model)

Objective A: Verify the presence of a Norton surface wave and the existence of an end-fire radiation mode.

Results: The existence of an end-fire pattern was verified indicating that the appropriate vertically-polarized surface wave had been established.

Objective B: Measure the azimuthal radiation pattern over 360° and verify the existence of a figure-eight radiation pattern.

Results: A high integrity pattern was observed. Maxima and minima are symmetrical in azimuth and properly separated by 180° ($\pm$ 3°). The absolute maxima levels match within a fraction of a dB; nulls match within 2 dB. These results furthur verify the integrity of the model.

Objective C: Measure azimuthal pattern data repeatability with the dipole fixed (quiescent) in the model material and with the dipole removed and then reinserted (dynamic) in the same location.

Results: Quiescent data repeat to within $\pm$ 0.5 dB; dynamic data repeat to within $\pm$ 1.5 dB.

Objective D: Measure the relative difference between the desired vertical polarization component of the field and the horizontal component at an elevation test angle of 5.5°. (This is the lowest elevation angle that can be accommodated when using a balanced, vertical dipole probe antenna).

Results: A 12 dB difference exists between the maximum vertical and horizontal response levels; this is a furthur indication of the validity of the model.

Objective E: Observe the effects produced by tilting the scaled dipole antenna elements down 12° and 3° in the vertical plane to simulate the element droop of the present NS antenna.

Results: No effects were noted.

Series 2: Modeled Mountain Tests

Objective A: Determine the azimuthal radiation patterns for the scaled dipole located on rectangular and hexagonal models of the Site A mountain with north-south (NS) and east-west (EW) orientations of the dipole. The rectangular model has dimensions of $\lambda/4 \cdot \lambda/2$ with the $\lambda/2$ dimension oriented north and south. The hexagonal model has dimensions of $0.23\lambda \times 0.1\lambda \times 0.16\lambda \times 0.1\lambda \times 0.2\lambda$. The modeled Site A mountains are 3 cm high above the level material representing about a 1500 foot MSL elevation.

Results: For the $\lambda/2 \times \lambda/4$ rectangular model, both the NS and EW orientations produced symmetrical figure-eight patterns with the proper 90° azimuthal displacement. However, the NS pattern maxima were some 2 dB greater than the EW maxima and of greater integrity, i.e., deeper nulls and better-formed maxima. This may be due to the fact that, for the EW orientation, a vertical air-material interface is very close to the ends of the dipole implying that a large negative terrain gradient near the ends of a buried dipole may not be desirable.

Objective B: Ascertain the effects of various antenna element droop angles on the relative characteristics and radiation pattern. A droop in the vertical plane simulates the placement of the dipole elements on the sides of the mountain with the feedpoint near the crest.

Results: Droop angles must exceed 20° - 30° before significant effects are noted. The actual droop angles of a dipole antenna located on the Site A mountain with a feedpoint at or very near the crest are less than 20°.

Objective C: Observe the effects of a simulated above ground operations area and above ground conductors.

Results: Effects of the simulated above ground operations area were insignificant; however, a simulated above ground conductor produced considerable pattern distortion and efficiency reduction especially when oriented parallel to the buried dipole. The simulated conductor was a 10 cm length of #18 AWG wire with a 40 mil diameter; this simulates an 8 meter diameter conductor at 58.7 kHz.

Objective D: Measure quiescent data repeatability as described under Series 1.

Results: Quiescent data repeated to within $\pm$ 0.5 dB.

Series 3: Modeled Mountain and Mountain Range Tests

Objective A: Determine the effects of a modeled NNE-SSW mountain range for both NS and EW dipole orientations on the hexagonal model of the Site A mountain. The range simulation was $\lambda/2$ wide and $\lambda/20$ high. The total extent was approximately 3.8λ from NNE (30^{o}) to SSW (216^{o}). The range was modeled by adding $\lambda/2$ segments in sequence starting at the circumference of the model and working toward the center. After each segment was added, azimuthal patterns of the NS antenna were recorded.

Results: The more remote $\lambda/2$ segments near the circumference had no effect on the pattern and efficiency; however, as more segments were added and the ridgeline extended toward the center, the pattern began to distort at azimuths near 30^{o} and 216^{o}. A peak distortion of 2 dB was recorded with the complete simulation. The EW dipole pattern also exhibited similar pattern distortions.

Objective B: Observe the effects of scaled simulations of the above and below ground operations areas and the above ground cabling (within the security fence) on the Site A mountain. The hexagonal model of the mountain was used.

Results: Simulations of the above and below ground operations area produced no significant effects. However, when the simulated above ground facility was moved to the ends of the dipole, significant (6-8 dB) null fill-in occurred; but no effect on the pattern maxima was noted.

The above ground cabling was simulated by a network of #32 AWG enameled wire grounded to the material at the appropriate points. Significant pattern effects were noted for both EW and NS antenna orientations with the major distortions occurring with the EW orientation. It should be noted that a large portion of the above ground cabling runs parallel to the EW dipole. The distortion effects were considerable; null fill-in (8-10 dB), null shift (10^{o} - 20^{o}), and alteration in the maxima levels (2-3 dB). The NS dipole effects were primarily null fill-in (6-8 dB) without null shift and maxima level disturbance.

Objective C: Measure the effects produced by inclining the EW dipole in the vertical plane to simulate placement of the feed point on the mountain side rather than near the crest. The east element was tilted up in the vertical plane; the west element was tilted down by the same amount, i.e., the EW dipole was inclined to "face" westward. Inclination angles of 8^{o} and 16^{o} were compared to the level (0°) configuration. Sixteen degrees is the maximum inclination angle that can be obtained on the Site A mountain. The modeled mountain had $\lambda/4 \times \lambda/4$ dimensions in the horizontal plane and was $\lambda/20$ high.

Results: For the level configuration the east radiation level exceeded the west level by some 3 dB. At an 8° inclination angle, the east level exceeded the west level by 1 dB. At a 16° inclination angle, the west level exceeded the east level by 1 dB. Therefore, overall, an inclination of 16° reduced the east level by some 2 dB and increased the west level by about 2 dB for a total change of some 4 dB in the pattern levels.

Objective D: Measure quiescent and dynamic data repeatability as described under Series 1. The hexagonal Site A mountain model was used.

Results: Quiescent data repeated to within $\pm$ 0.5 dB; dynamic data repeated to within $\pm$ 1.0 dB.

Overall Implications of the Initial Effort

The initial series of tests indicate the following.

1. The modeling technique using an 8000:1 scale factor, a scaled dipole, and a 7:5 mix of graphite and sand is valid and produces high integrity radiation characteristics.

2. Dynamic data repeatability using the model is about $\pm$ 1.5 dB.

3. Rapid terrain fall-off near the ends of a buried dipole may produce significant radiation pattern variations.

4. Dipole element droop angles must exceed some 20° - 30° before significant alterations in the radiation characteristics occur. Typical element droop angles on the Site A mountain are considerably less than 20°.

5. It appears that the directivity of a buried dipole antenna can be changed by inclining the antenna in the vertical plane. Placement of the EW dipole on the western slope of the Site A mountain may enhance the radiation to the west.

6. The Site A above and below ground operations areas have minimal effects on the radiation characteristics. However, above ground cabling could have considerable effect especially on the EW antenna.

7. The effects of local topography on the radiation characteristics are discernible but may be secondary compared to other very near-field effects.

20:1 Scaled-Dipole Investigation

Soil conductivity measurements were made at the proposed 20:1 scale model antenna measurement site. Surface measurements on a rectangular plot 5.5m by 6m indicate an average surface conductivity of 4.3×10^{-3} mhos/m. A total of 53 measurements were made, and the spread was from 1×10^{-3} mhos/m to 8×10^{-3} mhos/m.

Conductivity measurements were also made on the same site at a depth of 10 cm. These data indicated an average soil conductivity of 4×10^{-3} mhos/m. The spread was also from 1×10^{-3} mhos/m to 8×10^{-3} mhos/m.

These data were determined at a frequency of 1.12 MHz, and the results obtained are typical for the type soil at the site. No further conductivity measurements at the site are presently planned.

Site A Mountain Model

The fabrication of a scaled model of the mountain is 75 percent complete. The model will be approximately 38 cm high with a 4:1 vertical exaggeration. An additional model is also being fabricated. This model will be approximately 0.6m x 0.4m x .04m high with no vertical exaggeration. Urethane, plaster of paris, and fiberglas are being used to construct the models.

Conferences

On March 4 - 6, 1974, Mr. W. P. Czerwinski visited EES for a review of project activities and discussions of future efforts.

Work During Next Interval

During April, a complete simulation of the topography within a radius of 2λ from Site A will be added to the model and the effects evaluated. Work will continue on the model fabrication.

Respectfully submitted:

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

HHJ:swg

File: A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

3 May 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 4, Project A-1593, "Buried Dipole Antennas," Contract DAAB07-74-C-0103, 1 April to 1 May 1974.

Sir:

During April, significant progress was made on the 8000:1 scale model and the scaled dipole input impedance measurements.

Scale Model Investigations

A complete simulation of the topography within a radius of 2.3λ from Site A was completed on the model, and azimuthal radiation patterns were measured for both North-South and East-West dipole orientations. Terrain effects are quite evident and produce reductions in field strengths near terrain irregularities such as mountain/valley interfaces. Pattern distortions as large as 2 dB were observed. Data from the full-terrain characterization show that the northern and eastern radiation maxima are approximately the same level; however, the southern and western maxima are lower by several dB. Also, the North-South orientation exhibits higher quality radiation characteristics than the East-West orientation; the nulls are deeper and better formed. A major implication is that, if a full-scale East-West antenna were placed on Site A, its radiation characteristics will be no better than the present North-South antenna, and there is a strong likelihood the East-West pattern may be poorer than the North-South. For the modeled East-West antenna better directivity exists to the East.

Additional tests have shown that the East-West directivity can be equalized and pattern quality improved by moving the feedpoint toward the East and, hence, separating the western end of the East-West antenna from the edge of a sharp terrain gradient on the western slope of the Site A mountain.

A quick-look analysis has been performed on all of the data collected on the 8000:1 model. Table I presents a summary of the relative effects of various very near-field and near-field factors as determined using the model. An effect was defined as being very significant if pattern variations exceeded several dB near the maxima and at azimuths out of the null region. An effect was defined as being significant if patterns variations in the order of 1-2 dB were noted near the maxima. An effect was defined as being discernible if any variation in the pattern was observed; usually "discernible effects" were manifest as pattern null fill-in and skew.

Table I indicates that, overall, very near-field effects such as topography and above ground cabling have a relatively large impact on the buried antenna radiation characteristics especially if the antenna orientation is East-West.

Input Impedance Measurements on Scaled Dipole

Work has begun on measuring the input impedance of the scaled dipole in the modeled earth for various element tilt angles and dielectric insulations on the element. A 0.3 m x 0.3 m x 0.1 m test bed has been constructed to contain the material and the scaled dipole. Measurements will be made using the GR1710 RF network analyzer.

Briefing and Conference

On April 30 and May 1, 1974, Georgia Tech briefed representatives of USAECOM, USACEEIA, USACSA, and U. S. Army TELECOM on the results of the modeling investigation. The impact of the results on the projected placement of the East-West antenna on Site A were discussed by the briefing participants.

Georgia Tech provided a complete data packet to the briefing attendees.

Work During Next Interval

During May, work will continue on measuring the input impedance characteristics of the scaled antenna. Also, work will begin on the instrumentation for the 20:1 scaled dipole investigation.

Respectfully submitted:

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

EFFECT → / FACTOR ↓	VERY SIGNIFICANT	SIGNIFICANT	DISCERNIBLE	NEGLIGIBLE
VERY NEAR-FIELD TOPOGRAPHY	● *			
VERY NEAR-FIELD CONDUCTORS ABOVE GND.	● *			
VERY NEAR-FIELD ABOVE GND. OPS. AREA			●	
VERY NEAR-FIELD BELOW GND. OPS. AREA				●
VERY NEAR-FIELD BELOW GND. CONDUCTORS				●
ANTENNA ELEMENT DROOP/TILT			●	
ANTENNA INCLINED ON SLOPE	●			
NEAR-FIELD TOPOGRAPHY		●		

* Especially for East-West orientation

TABLE I. SUMMARY OF MODELING RESULTS

File: A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 June 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 5, Project A-1593
"Buried Dipole Antennas", Contract DAAB07-74-C-0103
1 May to 1 June 1974.

Sir:

Experimental investigations of buried dipole antenna performance have continued at a steady pace during May. Specific efforts using the 8000:1 scale model include studies of the following:

- Effects of Very Near-Field Terrain Gradients
- Effects of Dielectric Sheathing on the Antenna Elements

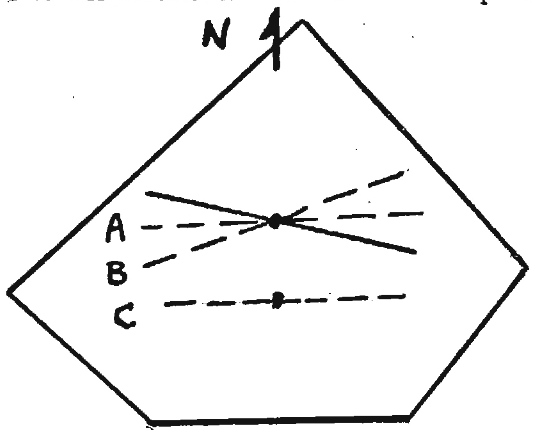
Instrumentation for obtaining the elevation plane radiation patterns has been completed. Measurements on the asphalt sample from the Site A mountain have been completed.

Effects of Very-Near Field Terrain Gradients

Tests on the scaled East-West antenna have indicated that the relatively sharp terrain gradient on the western slope of the Site A mountain may have an adverse effect on the westward radiation efficiency of the East-West antenna. Modeling results show that the western radiation is some 2-3 dB less than the eastern radiation.

Tests using the 8000:1 model have shown that the East-West directivity can be equalized and the pattern quality improved by orienting the East-West antenna such that there exists more level terrain off of the western tip of the East-West antenna.

The tests were accomplished by investigating various locations of the East-West antenna on the modeled Site A mountain. The diagram below depicts a top view of the Site A mountain modeled as a pentagon.



Scale 1" ≐ 2000'

The solid line indicates the location of the scale model East-West antenna on a 282° bearing. The dashed lines (A, B, and C) represent three other test orientations. It may be noted that the western tip of the 282° antenna is very close to a simulated terrain gradient. For orientations A, B, and C, the western tip is separated from the terrain gradient, and more level terrain exists off of the end. Test data show that, for all three orientations (A, B, C), the East and West radiation pattern directivity values are essentially the same. This implies that sharp terrain gradients near the antenna element ends should be avoided.

Effects of Dielectric Sheathing on the Antenna Elements

Dielectric sheathing was placed around the 8000:1 scaled buried antenna elements, and the effect on relative efficiency and radiation pattern characteristics was measured.

Two sizes of dielectric sheathing were used. One, had an inside diameter of 0.032 inches and an outside diameter of 0.125 inches. The other had an I. D. of 0.008 inches and an O. D. of 0.0667 inches. The material was vinyl with a dielectric constant of 2.8.

The sheathing with an I. D. of 0.008 inches fit tightly around the #32 AWG antenna element wire whereas the sheathing with an I. D. of 0.032 inches fit quite loosely and hence afforded an air gap between the element and sheathing. It should be noted that, on a full-scale antenna, the corresponding O. D.'s of the full-scale sheathings are roughly 80 feet and 40 feet for the 0.125 inch and 0.0667 inch scaled sheathings, respectively. Therefore, we are modeling relatively large dielectric sheathings.

For both sheathings, the efficiency of the East-West antenna improved. For the larger diameter sheathing with air gap, the improvement was about 2.5 dB in the westward direction and 2 dB in the eastward direction. For the smaller diameter sheathing with no air gap, the efficiency increase was 2 dB in the westward direction and 1 dB in the eastward direction. For both sheathings, the pattern characteristics (shape and null depth) are essentially the same.

It is interesting to speculate on the greater improvement in the western directivity. Is it possible that a buried antenna which is sheathed with a dielectric is less susceptible to irregularities in the media near the element ends?

Input Impedance Measurements on Scaled Dipole

This effort has been hindered by a malfunction of the GR1710 Network Analyzer. The unit has been returned to the factory, and expedited repair has been requested.

Elevation Plane Radiation Pattern Instrumentation

Elevation plane patterns will be measured by locating a battery-powered 470 MHz signal source at selected elevation angles relative to the buried antenna model.

Design and development of the compact signal source have been completed. This device uses three-stage discrete circuitry consisting of an oscillator stage and two stages of power amplification feeding a balanced, resonant dipole. Output power is about +15 dBm.

Initial elevation pattern measurements have been made. Data indicate that the patterns are smooth and exhibit no lobing effects.

Measurements on Asphalt Sample

Measurements of the dielectric constant, loss tangent, and conductivity for the asphalt sample obtained from the Site A North-South antenna location have been completed. Data indicate that, at 60 kHz, the relative dielectric constant should be approximately 3 and the conductivity about 2×10^{-6} mhos/meter. These results imply that the asphalt "sheathing" around the present North-South antenna is a relatively lossless dielectric. Also, since asphalt is inherently nonhydroscopic, this "sheathing" should be effective in providing a good dielectric environment in the immediate proximity of the buried dipole antenna.

Work During Next Interval

During June, major effort will be on the elevation pattern measurements.

Respectfully submitted:

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

HHJ:swg

File. A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 July 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 6, Project A-1593, "Buried Dipole Antennas", Contract DAAB07-74-C-0103, 1 June to 1 July 1974.

Sir:

Elevation Plane Radiation Patterns

Elevation plane radiation patterns have been measured on the North-South and East-West antennas using the 8000:1 scale model. Full terrain characterization and the pentagonal model of Site A were used.

Elevation plane patterns were obtained by locating a battery-powered 470 MHz signal source at elevation angles (Φ) of 6^{o}, 12^{o}, 18^{o}, 24^{o}, 30^{o}, 40^{o}, 50^{o}, 60^{o}, 70^{o}, and 90^{o} relative to horizontal and measuring complete 360^{o} azimuthal radiation patterns at each elevation angle. In this manner elevation plane patterns can be derived for any azimuth angle.

Figure 1 depicts the elevation pattern in the North-South plane for the North-South antenna. Levels on the pattern are referenced to the 6^{o} level in the northern direction. The radiation pattern is essentially as predicted by theory; deviations, such as the reduced response near 40^{o} elevation angle, are probably due to terrain effects.

Figure 2 depicts the elevation pattern for the East-West antenna in the East-West plane. The levels are referenced to the 6^{o} level in the eastern direction. Here again the measured pattern coincides closely with the theoretical except for the slight lobing effect near 30^{o} which is probably terrain effects.

Overall, the elevation plane patterns are well-behaved and correspond quite closely to the expected results. A major point is that, for the East-West antenna, no lobes exist which would tend to improve the westward directivity.

Work During Next Interval

During July, it is anticipated that the GR1710 Network Analyzer will be returned from the factory, and that the input impedance measurements on the scaled dipole can be completed.

Work will begin on the 20:1 scaled dipole antenna investigation.

Respectfully submitted:

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

HHJ:swg

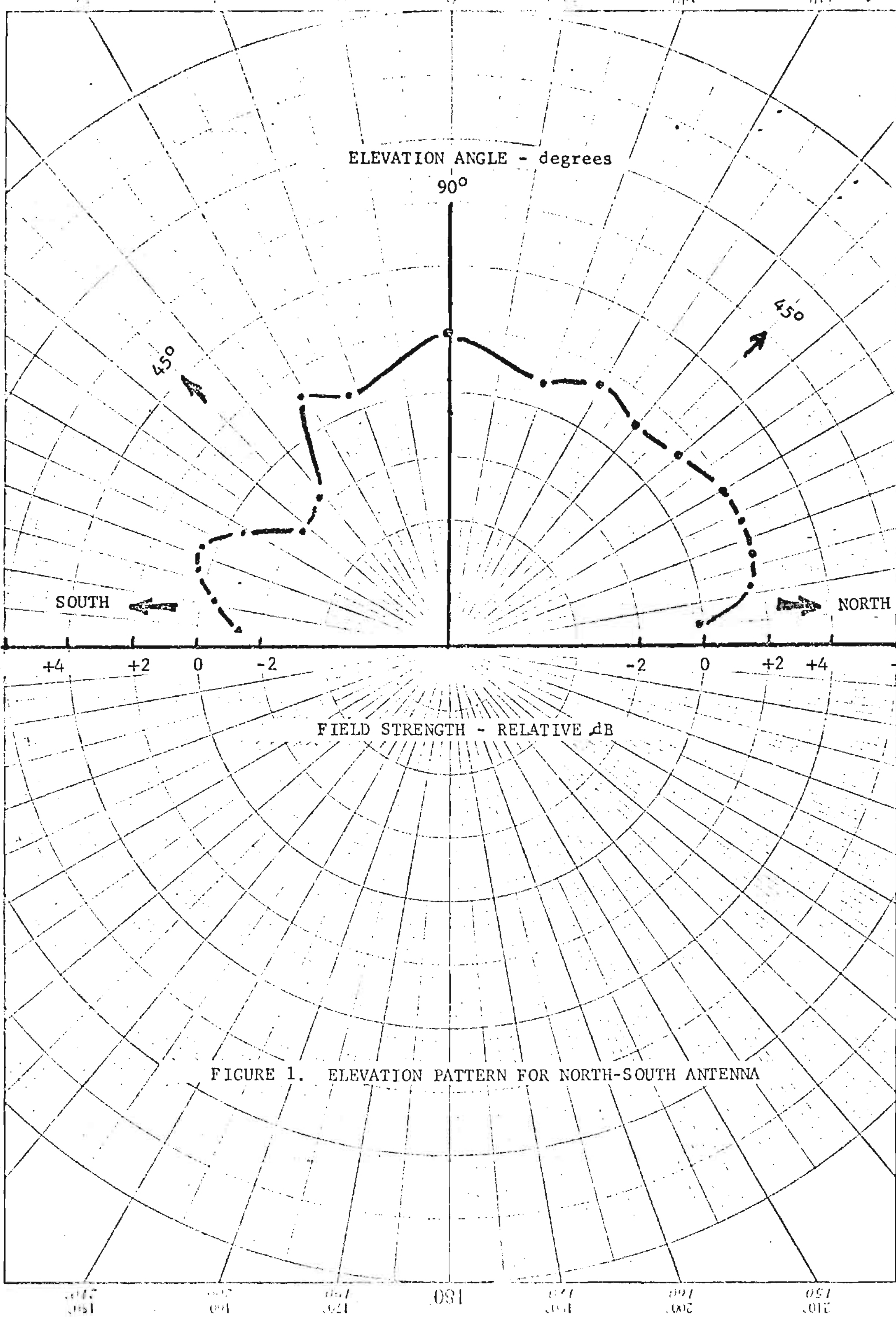


FIGURE 1. ELEVATION PATTERN FOR NORTH-SOUTH ANTENNA

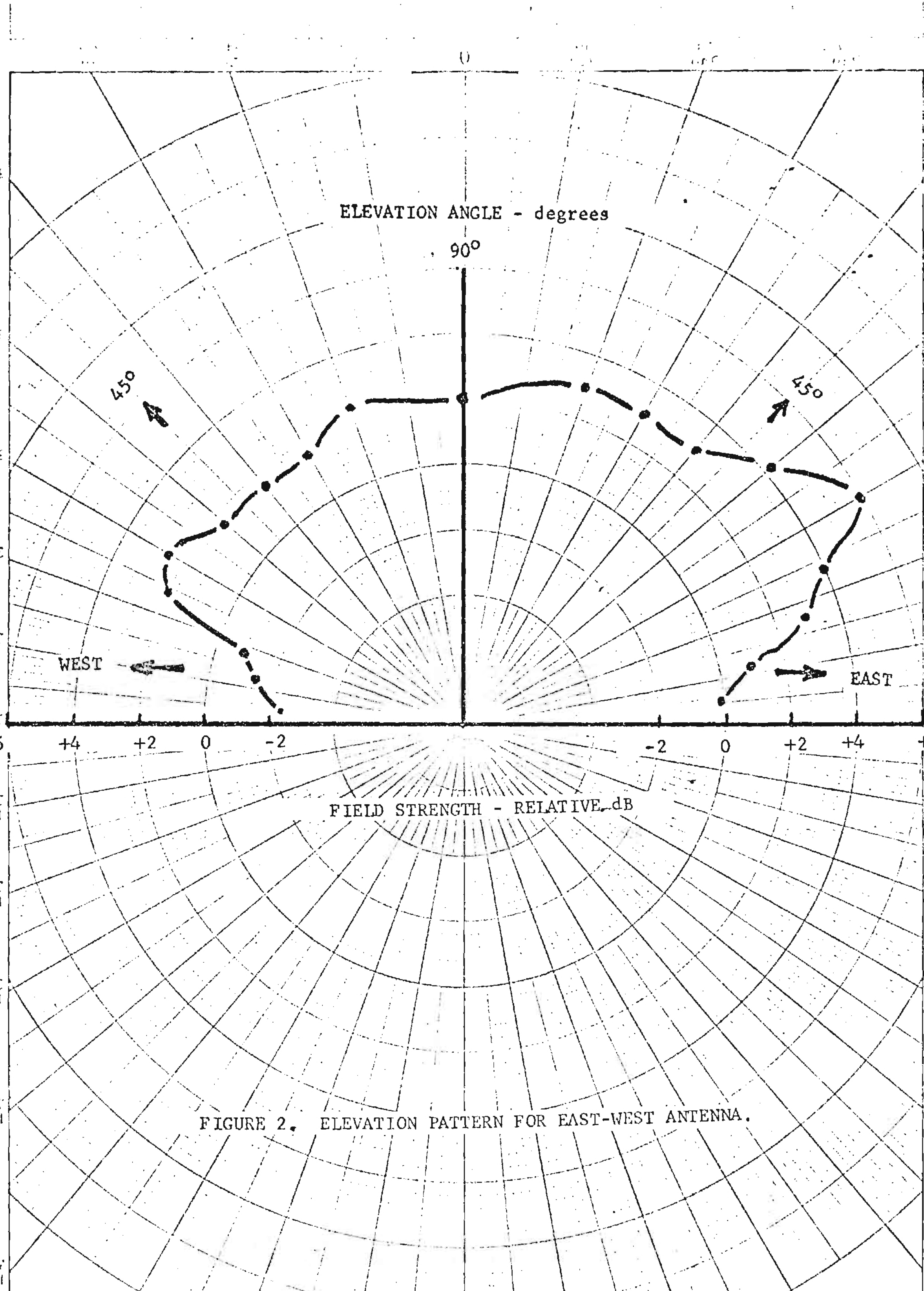


FIGURE 2. ELEVATION PATTERN FOR EAST-WEST ANTENNA.

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GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 August 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
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Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 7, Project A-1593, "Buried Dipole Antennas," Contract DAAB07-74-C-0103, 1 July to 1 August 1974

Sir:

During July progress was made on (1) experimental investigations using the 8000:1 scale model and (2) preparations for the 20:1 scale model effort.

Radiation Patterns for EW and NS Buried Dipole Antennas Combined to Provide An Omnidirectional Pattern

It may be shown that buried dipole antennas which are 90 degrees apart in both space and time and fed with equal amplitude signals exhibit an omnidirectional pattern in the azimuthal plane.

Therefore, a scaled model of combined EW and NS buried dipole antennas has been constructed and phasing circuitry developed to provide an azimuthal "omnidirectional" pattern devoid of deep nulls.

The antennas are identical replicas of the single scaled antennas aligned in a perpendicular orientation.

The phasing network developed consists of a quadrature coupler feeding broadband unbalanced-to-balanced transformers. The transformer outputs feed the two crossed dipoles. The quadrature coupler is a Merrimac QHF-2-0.375G unit with a frequency range of 250-500 MHz, rated amplitude unbalance of $\pm$ 0.5 dB, and rated phase differential of 90° $\pm$ 2°. The transformers are Vari-L HYB-1 units rated from 0.25-500 MHz with nominal amplitude and phase unbalance of 1 dB and 5° respectively. Measured values of the overall amplitude and phase unbalance between the dipole inputs are approximately 3.0 dB and 10° respectively.

Figure 1 depicts the measured azimuthal radiation pattern at a 5° elevation angle for the combined dipoles. Full terrain characterization and the pentagonal model of Site A were used. The relative dB scale is such that the nominal null depths for the individual NS and EW antennas reach to the center of the graph at -28 dB. Overall, the pattern is reasonably omnidirectional. A large part of the NS elongation is probably due to the amplitude and phase unbalance between the dipole input signals. Also terrain and siting effects may be influencing the NS "directivity."

Evaluation plane patterns were obtained by locating a battery-powered 470 MHz signal source at elevation angles of 6°, 12°, 18°, 24°, 30°, 40°, 50°, 60°, 70°, and 90° relative to horizontal and measuring complete 360° azimuthal radiation patterns at each elevation angle. In this manner elevation plane patterns can be derived for any azimuth angle.

Figure 2 depicts the elevation pattern in the North-South plane. Levels on the pattern are referenced to the 6° level in the northern direction.

Figure 3 presents the East-West plane pattern. Levels on the pattern are referenced to the 6° level in the eastern direction. Semi-hemispherical coverage in both planes is present without serious lobing effects although variations approaching 4-6 dB are evident at the lower elevation angles. This could very well be siting and terrain induced effects.

For the East-West plane, enhanced eastern radiation relative to the western level is manifest. This correlates with the East-West radiation pattern for the individual East-West antenna (Figure 2 of Monthly Status Report No. 6).

Overall, the model radiation patterns indicate that "omnidirectional" coverage in both azimuth and elevation may be obtained by the use of buried East-West and North-South dipoles and appropriate input signal phasing. However, careful control over amplitude match and 90° phasing must be exercised in order to obtain high integrity omnidirectional patterns.

Preparation for 20:1 Scale Model Experiment

Preparations are underway for the 20:1 scale model experiment. Local broadcast signal strengths are being measured at the site and instrumentation checked-out.

8000: 1 Scaled Dipole Input Impedance Measurements

The GR1710 Network Analyzer has been returned from the factory, and input impedance measurements are being made.

Review of VLF Propagation Measurements

A review of the ACCC-CED-RPE VLF propagation measurements has been performed. It was interesting to note that the 8.5 dB measured value (March 1974) of signal attenuation at 60 kHz corresponds very closely to our calculated value of 8.8 dB for $\sigma = 10^{-4}$ mhos/m, which was the full-scale σ value used for our materials modeling.

Work During Next Interval

During August, the major emphasis will be on the 20:1 model testing and the measurement of input impedance for the 8000:1 scaled dipole.

Respectfully submitted:

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

HHJ:jel

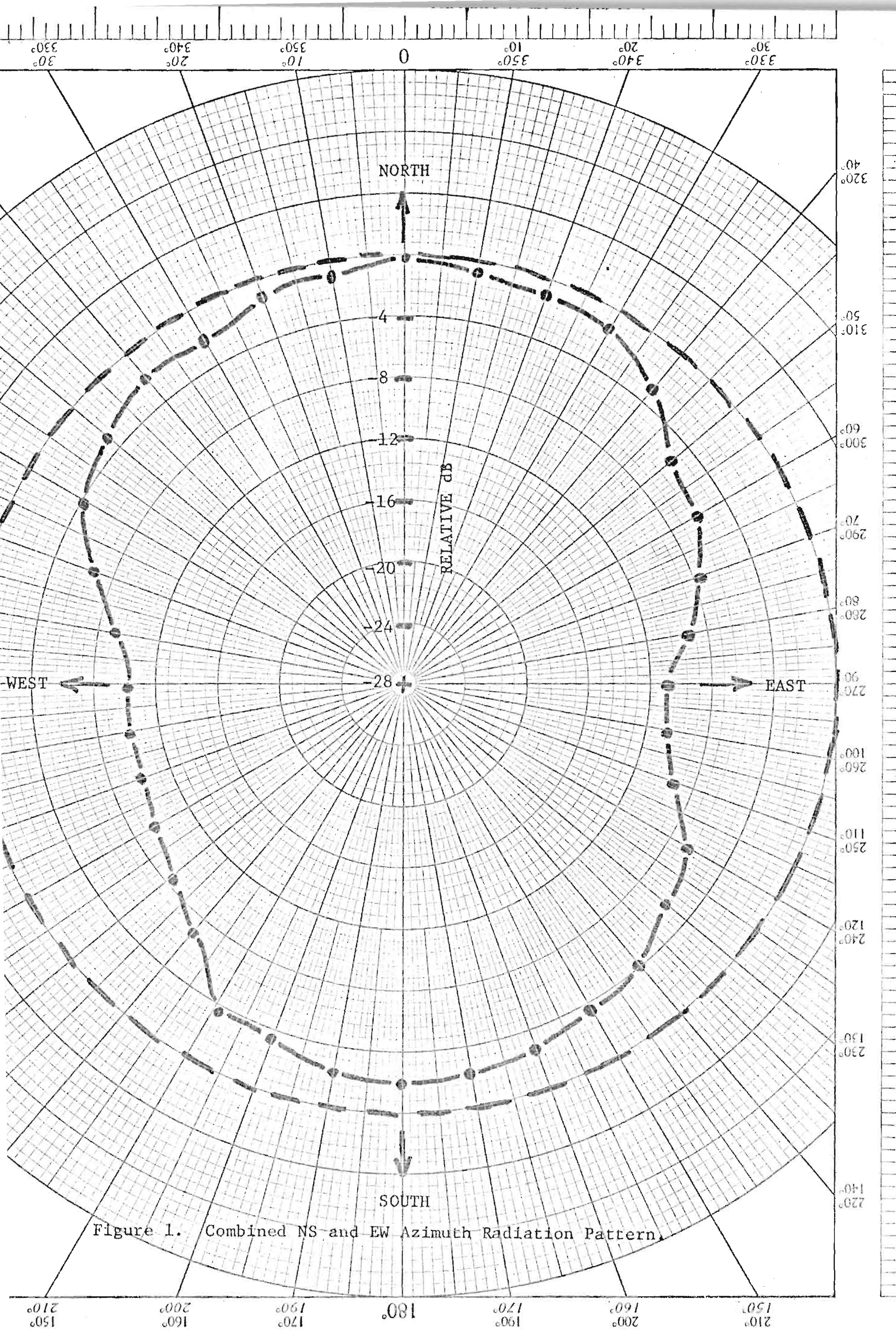

Figure 1. Combined NS and EW Azimuth Radiation Pattern.

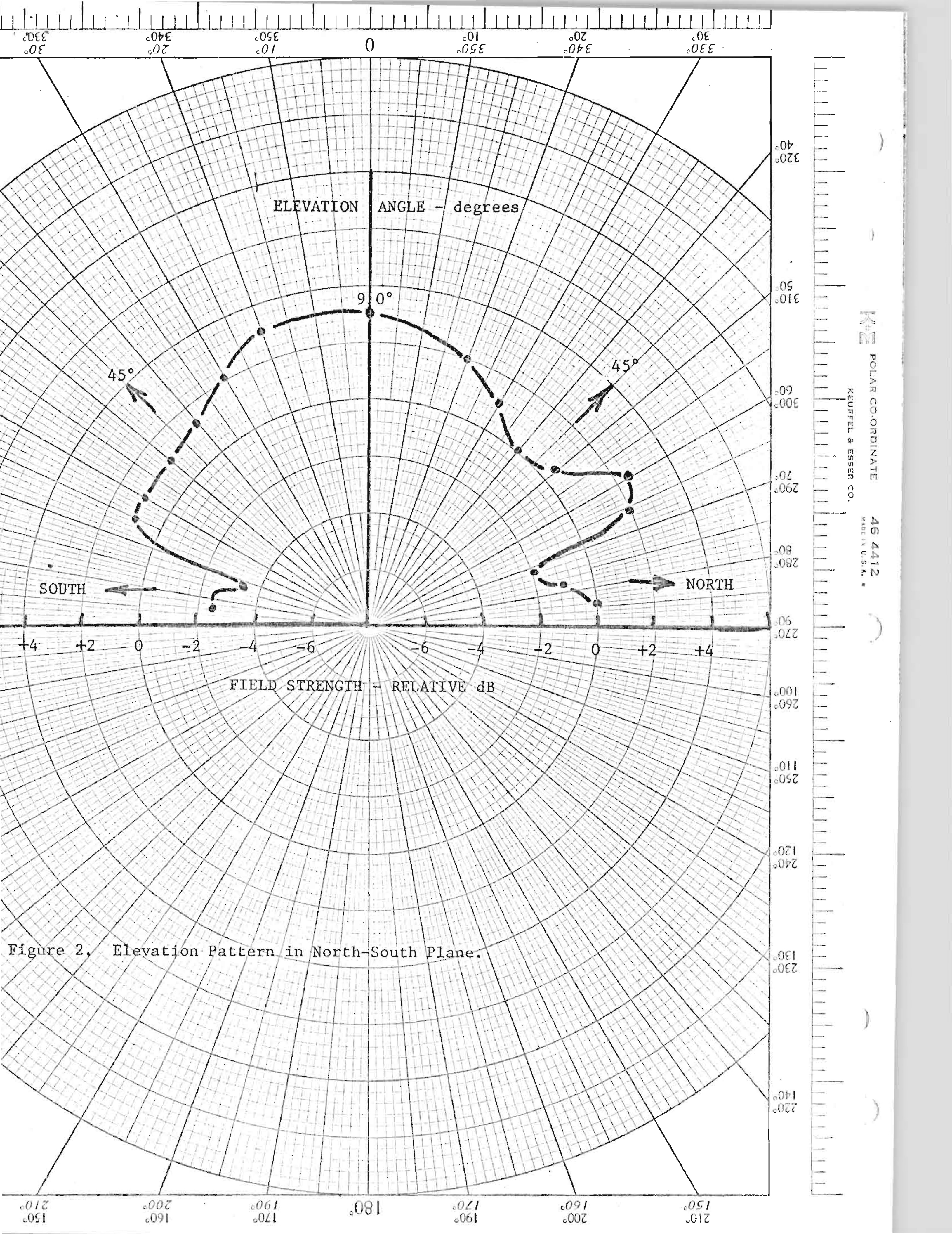

Figure 2, Elevation Pattern in North-South Plane.

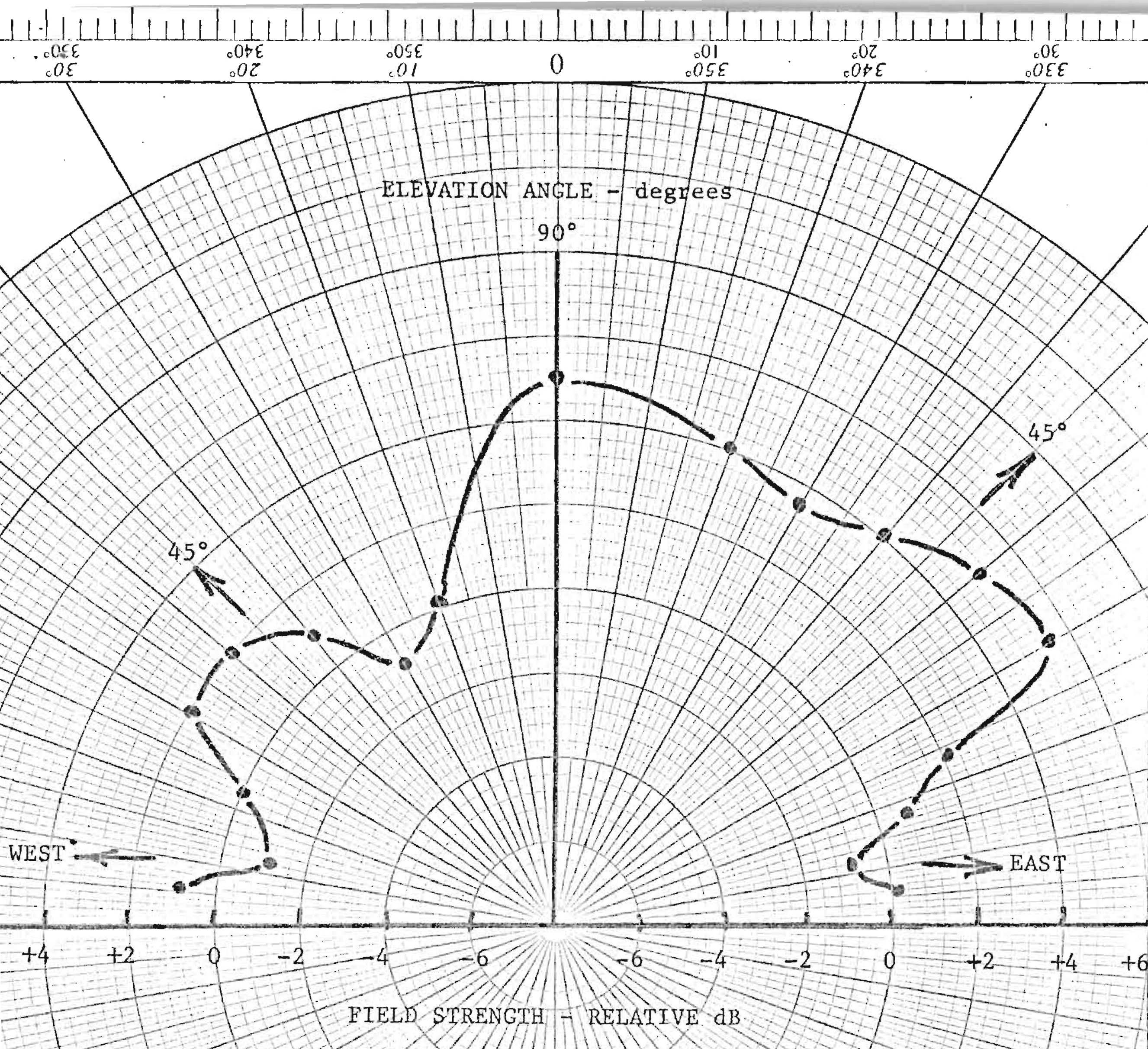

Figure 3. Elevation Pattern in East-West Plane.

File A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 September 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 8, Project A-1593, "Buried Dipole Antennas," Contract DAAB07-74-C-0103, 1 August to 1 September 1974.

Sir:

During August, progress was made on (1) obtaining input impedance measurements on the 8000:1 scaled dipole antenna, and (2) preparations for tests on the 20:1 scale model of the Site A buried antenna.

Input Impedance Measurements

Input impedance measurements have been made on the 8000:1 scaled dipole antenna at the following locations relative to the modeled-earth material (Graphite/Sand; 7:5).

1. Above the material; 1 inch in the air.
2. On the surface of the material.
3. Just under the surface of the material.
4. 0.5 inches under the surface of the material.
5. 0.5 inches under the surface of the material with a 0.125" O. D. dielectric ($\epsilon_r = 2.8$) sheath.
6. 0.5 inches under the surface of the material with a 0.067" O. D. dielectric ($\epsilon_r = 2.8$) sheath.
7. 0.5 inches under the surface of the material with dipole element tilt angles of 3^o, 12^o, 18^o, 22^o, 45^o, and 60^o relative to horizontal.

The material test bed was 12" wide and 12" long with a material depth of 3". The scaled dipole was fed by a 4" length of RG-194. Input impedance measurements were made at 470 MHz at the output of the RG-194 feedline and translated to the scaled antenna input terminals by use of the Smith Chart. At 470 MHz, the electrical length of the RG-194 cable is 0.23λ. Measurements were made using the GR1710 Network Analyzer.

The following lists the normalized (50 ohms) antenna input impedance as a function of its location relative to the material.

Location	$\bar{Z}/50\ \Omega$ (ohms)
1. Above Material	0.5 - j 2.2
2. On Surface	0.8 - j 1.8
3. Just Under Surface	1.6 - j 0.9
4. 0.5" Under Surface	2.6 - j 0.2

The above normalized impedances are shown plotted on Figure 1 and connected by a dashed line to indicate the impedance path between the four discrete locations. In air, the sealed dipole is an electrically-short antenna as manifest by the relatively large capacitive reactance; however, when immersed in the material, the input impedance is resistive (~130 Ω) indicating a resonant effective-length condition. These results are encouraging in that they imply that the modeled earth material is providing a good simulation of the actual earth conditions.

With large diameter dielectric sheathing the input impedances are as follows:

Dielectric O. D. (in)	Input Impedance
0.125	0.72 - j1.18
0.067	0.7 - j1.1

These are plotted as points No. 5 and 6 on Figure 1. The major implication is that large dielectric sheathings around a buried antenna reduce the effective electrical length and, hence, can reduce a resonant mode to a nonresonant mode as manifest by the large reactance component with the dielectric sheathing. Another implication is that, for relatively large sheathings, an increase in sheathing diameter has little effect on the antenna input impedance. A 2:1 increase in sheathing diameter changed the impedance less than 10%.

The effect of antenna element angle tilt on input impedance was negligible at 3^{o}, 12^{o}, 18^{o}, and 22^{o}. At 45^{o} the input impedance changed slightly to 2.1 - j 0.4 from 2.6 - j 0.2. At 60^{o}, the input impedance was 3.2 - j 1 - a significant impedance variation. Tests were performed for both flat and conformal material, i.e., for one test the material at the air/material interface was maintained horizontal and for the conformal tests the material was shaped to follow the contour of the element tilt. Test results for the two cases were, for all practical purposes, identical.

The tilt angle tests imply that the effects of antenna element deviation in the elevation plane from the horizontal due to terrain gradients should be negligible.

Preparation for 20:1 Scale Model Experiment

Four ditches 142 feet long have been dug for the 20:1 scaled model buried antenna experiment. The nominal ditch depths are 3", 6", 9" and 12". A 20:1 scale model antenna has been constructed, and test instrumentation is being prepared for the tests. Instrumentation includes: (1) the GR 1710 automatic network analyzer for the input impedance tests; (2) the EMC-25 field intensity meter for the efficiency and current distribution tests; and (3) the HP 606 as a drive source for current distribution testing.

Work During Next Interval

During September, work will begin on the field evaluation of the 20:1 scaled model antenna.

Respectfully submitted,

H. H. Jenkins
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

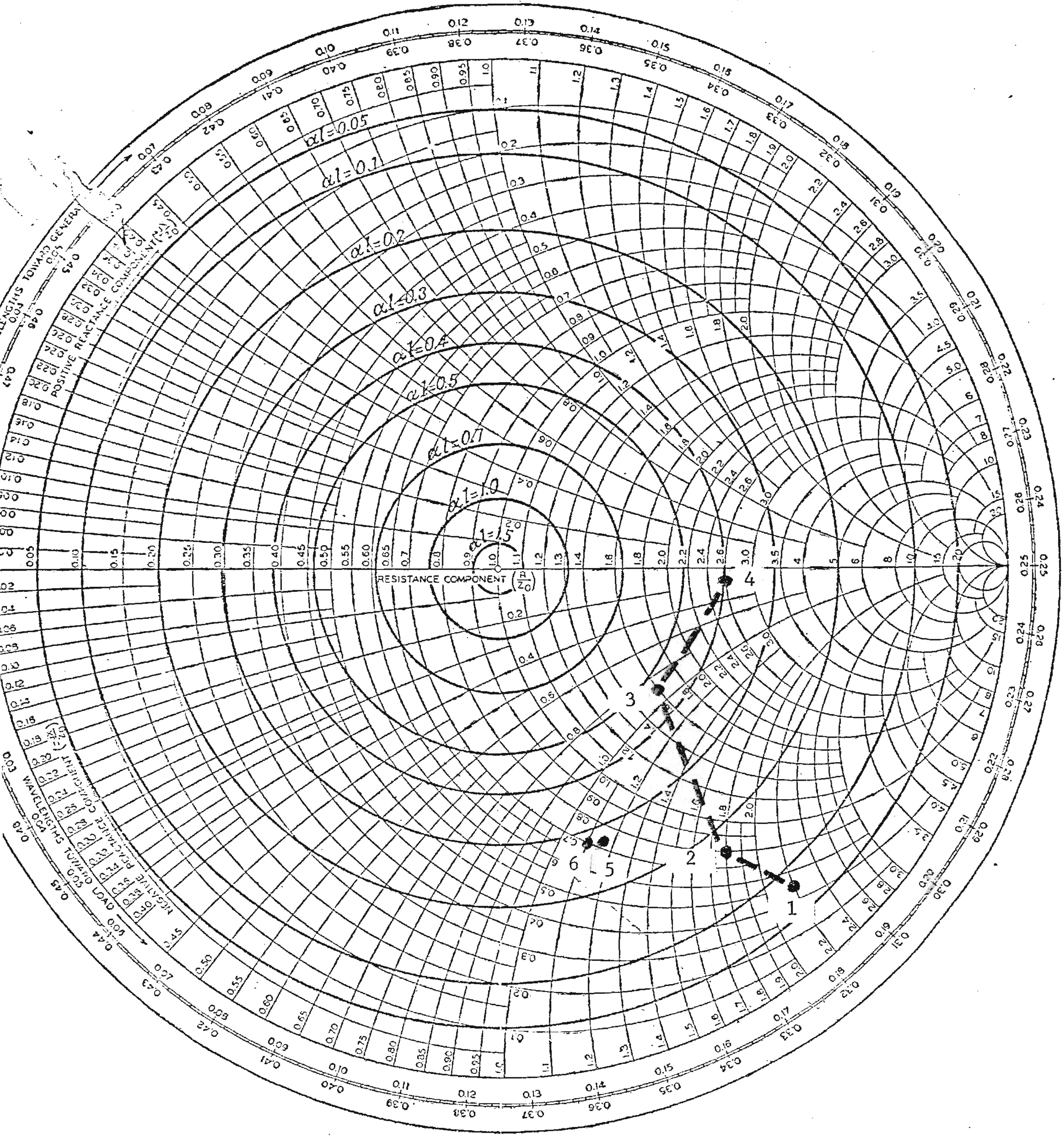

FIG. 1.—Polar impedance diagram.

File: A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 October 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 9, Project A-1593, "Buried Dipole Antennas", Contract DAAB07-74-C-0103, 1 September to 1 October 1974

Sir:

During September, significant progress was made on the 20:1 scaled model tests of the Site A dipole.

In preparation for the tests, the field intensity in volts/meter of eighteen AM broadcast band transmissions from 0.5 - 1.7 MHz has been measured at the 20:1 test location using a standard (loop) reference antenna and the EMC-25 Field Intensity Meter. These data are being used for the relative efficiency tests.

Table I presents a comparison between the pertinent parameters for the full-scale (Site A) antenna and the 20:1 model. It may be noted that the scaling is not perfect for each and every parameter but many of the critical parameters are scaled quite close to the desired values.

Tests performed to date include input impedance measurements with the antenna above the ground, lying on the ground, and buried at depths of 3", 6", and 9" and 12".

Complex input impedance was measured at various frequencies from 0.5 - 1.7 MHz using the GR1710 Network Analyzer. The test frequencies were 0.5, 0.7, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.6, 1.7 MHz and any resonant frequency within the 0.5 - 1.7 MHz range. Table II presents the resultant complex impedance data for various antenna placements.

Data for 6", 9", and 12" buried antenna depths were virtually identical to the 3" data with variation being less than $\pm$ 10%. This implies that a buried antennas attenuation (α) and phase (β) constants are independent of burial depth, h, if h is much less than one skin depth.

The data in Table II illustrates the significant effect that a transition across the air/ground interface has on the antenna input impedance and resonant length. Above the surface, the horizontal dipole was highly capacitive reactive indicating an electrically-short operating length. On the surface, the antenna was less reactive but there existed no resonance at or near the 20:1 scale frequency of 1174 kHz. However, below the surface a resonance occurred at about 1000 kHz. This implies that the propagation constants for the antenna vary greatly across an air/ground interface, and that the electrical loading imposed by the surrounding earth on the antenna is very effective in increasing the electrical length.

The measured resonance of the full-scale antenna occurs at 50 kHz with an input resistance of about 100 ohms. On the 20:1 model, the resonant frequency is 960 kHz, which is only 40 kHz below the theoretical scaled resonant frequency of 1000 kHz. The scaled resonant input impedance is 100 ohms. The close correspondence between measured and anticipated input impedance and resonant frequency strongly suggests that the 20:1 modeling technique is reliable even though some of the parameters do not scale exactly.

Work During Next Interval

During October, we will continue the 20:1 model tests with emphasis on the efficiency and current distribution of the subsurface antennas.

Conference

On 23 - 25 September 1974, Mr. W. P. Czerwinski, USAECOM, and Mr. Seymour Krevsky, USACSA, visited Georgia Tech for a review of project progress and discussion of future effort.

Respectfully Submitted,

H. H. Jenkins
Project Director

HHJ:swg

Approved:

D. W. Robertson, Chief
Communications Division

TABLE I

COMPARISON OF FULL SCALE AND 20:1 MODEL

Parameter	Definition	Full-Scale	20:1 Model	Ratio	Ideal Ratio
a	Antenna Wire Radius	0.31"	0.015	0.05	0.05
b	Antenna Dielectric Radius	1"	0.0625	0.0625	0.05
b/a	______	3.3(Note 1)	4.167	1.26	1
ϵ_r	Antenna Dielectric Constant	2.3	2.8	1.21	1
ϵ_r	Ground Dielectric Constant	10	10	1	1
σ	Earth Conductivity (mhos/m)	10^{-4}	4.3×10^{-3}	43	20
δ	Skin Depth (m)	207	7	0.034	0.05
f	Operating Frequency	58.7 kHz	1190 kHz	20.2	20
h	Antenna Burial Depth	18"	3" (min.)*	0.167	0.05
ℓ	Antenna length	2842'	142'	0.05	0.05
δ/a	______	2.7×10^4	1.8×10^4	0.67	1
h/δ	______	0.002	0.011 (min)	5.5	1
2h/b	______	36	98	2.73	1
β	Phase Constant	0.005	0.111	22	20
α	Attenuation Constant	0.00032	0.0042	13	20
α/β	______	0.064	0.038	0.59	1

* Other h values: 6", 9", 12".

Note 1: With the asphalt trench, the b/a ratio for the antenna at Site A is about 20.

TABLE II

DATA FROM INPUT IMPEDANCE MEASUREMENTS

Frequency (MHz)	Z @ θ Above Surface (Ohms)	Z @ θ On Surface (Ohms)	Z @ θ Three Inches Beneath Surface (Ohms)
0.5	1100 @ -90°	620 @ -90°	200 @ -65°
0.7	700 @ -90°	450 @ -85°	130 @ -50°
0.9	550 @ -80°	320 @ -70°	90 @ -20°
0.96	———	———	100 @ 0°
1.0	450 @ -75°	270 @ -70°	105 @ 0°
1.1	420 @ -75°	220 @ -65°	120 @ 10°
1.2	380 @ -75°	220 @ -65°	150 @ 20°
1.3	320 @ -75°	190 @ -60°	180 @ 20°
1.4	300 @ -70°	170 @ -55°	190 @ 20°
1.5	280 @ -70°	150 @ -50°	190 @ 15°
1.6	250 @ -70°	130 @ -45°	200 @ 10°
1.7	230 @ -65°	120 @ -40°	205 @ 10°

A-1593

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 November 1974

Mr. W. P. Czerwinski
AMSEL-NL-H-3
United States Army Electronics Command
Fort Monmouth, New Jersey 07703

Subject: Monthly Status Report Number 10, Project A-1593, "Buried Dipole Antennas", Contract DAAB07-74-C-0103 1 October to 1 November 1974

Sir:

During October, several significant investigations were completed using both the 20:1 and the 8000:1 scale models.

20:1 Scale Model

Input impedance, current distribution, and relative response tests were completed for both small and large antenna dielectric radius-to-antenna conductor radius ratios b/a. The small b/a ratio was obtained using a 0.015" wire radius covered with a .0625" insulation ($\varepsilon_r \doteq 2.8$). This provided a b/a ratio of 4.167. A larger b/a ratio was simulated by enclosing the above conductor and insulation in a water hose with an I.D. of 0.75" and an O.D. of 1". The larger b/a ratio is 33 in a three-layer dielectric configuration consisting of the 0.0625" radius insulation on the conductor, a 0.3125" radius air gap, and the 0.125" insulation of the water hose material (vinyl with an $\varepsilon_r \doteq 2.8$).

(The presence of the air gap may not afford a valid simulation of the full-scale antenna. Therefore, we have filled the water hose with ordinary, concrete-grade sand with an anticipated $\varepsilon_r \doteq 2.6$. This may be a better simulation of the asphalt trench around the buried antenna. Tests will be performed on this antenna in the early part of November.)

Input Impedance - Large b/a Ratio

Complex input impedance was measured at various frequencies from 0.5 - 2.2 MHz using the GR1710 Network Analyzer. Measurements were made with the simulated antenna lying on the surface and 1" below the surface. Table I presents the test results:

TABLE I

DATA FROM INPUT IMPEDANCE MEASUREMENTS - LARGE b/a RATIO

Frequency (MHz)	Z @ θ On Surface (ohms)	Z @ θ Below Surface (ohms)
0.5	760 @ -90°	400 @ -90°
0.7	500 @ -85°	300 @ -80°
0.9	360 @ -80°	195 @ -80°
1.0	300 @ -80°	160 @ -70°
1.1	280 @ -75°	150 @ -55°
1.2	210 @ -65°	110 @ -45°
1.3	190 @ -60°	100 @ -40°
1.4	180 @ -50°	95 @ -35°
1.5	185 @ -55°	85 @ -25°
1.6	180 @ -55°	80 @ -5°
1.63	----------	90 @ 0°
1.7	150 @ -55°	100 @ $+10^{\circ}$
1.95	100 @ -30°	----------
2.12	110 @ 0°	----------

Here, as in the case of the smaller b/a ratio, the transition across the air/ground interface increased the effective electrical length, and, hence, lowered the resonant frequency. However, the larger b/a ratio resonant frequency of 1.63 MHz is significantly larger than the smaller b/a ratio resonant frequency of 0.96 MHz. (See Monthly Status Report Number 9 for small b/a data.) Both the large and small b/a input impedances at resonance are about 100 ohms.

Current Distributions

Antenna element current distribution has been measured for both large and small b/a ratios in above and below ground configurations.

Measurements were made at the feedpoint, one-half and three-quarters of the distance to the ends of both elements, and at the element end points. The current probe was a Fairchild PCL-25 feeding an EMC-25 Field Strength Meter. The cabling between the probe and meter was 0.5 m long and perpendicular to the antenna element. The antenna was driven by a 0 dBm signal source at 1.2 MHz.

Table II presents the data with levels referenced to the feedpoint levels. In general, what exists is a quasi-sinusoidal decrease in current from feedpoint to element end. For a perfect sinusoidal distribution, the mid-point, three-quarter, and end currents should be -6, -8.3, and -∞ dB, respectively. It may be noted that the mid and three-quarter levels for all configurations are quite close to theoretical. At the end points in the above ground location, current levels are discernible above the ambient noise level (about -35 dB) indicating an electrically-short condition.

TABLE II

CURRENT DISTRIBUTION DATA

Ratio b/a	Probe Location on Element	Relative Current Level Antenna Location		
		Above (dB)	On (dB)	Below (dB)
Small	Feedpoint	0	0	0
	Mid-Point - N	- 5	- 5	- 5
	Three-Quarters - N	- 9	- 9	- 9
	End - N	-26	>-35	>-35
	Mid-Point - S	- 5	- 5	- 5
	Three-Quarters - S	- 9	- 9	- 9
	End - S	-29	>-35	>-35

(Continued)

TABLE II

CURRENT DISTRIBUTION DATA

Ratio b/a	Probe Location on Element	Relative Current Level Antenna Location Above (dB)	On (dB)	Below (dB)
Large	Feedpoint	---	0	0
	Mid-Point - N	---	- 6	- 4
	Three-Quarters - N	---	-11	-11
	End - N	---	>-35	>-35
	Mid-Point - S	---	- 5	- 5
	Three-Quarters - S	---	- 9	-11
	End - S	---	>-35	>-35

N: North Element
S: South Element

Relative Response Levels

The primary objective of the relative response tests was to determine the effect of burial depth on the amplitude response of the buried antennas using eighteen local broadcast signals as test transmissions. The broadcast signals ranged from 0.5 to 1.6 MHz and were geographically distributed as follows:

NE-6, NW-2, SE-3, NW-2, E-3, and N-2.

The relative responses were averaged for each configuration. Table III presents the results showing the average values and the range of values, which is shown within the parentheses. It should be remembered that the antenna length remained the same for all locations, and that above and on the surface, the antenna resonance falls above 1.6 MHz.

TABLE III

RELATIVE RESPONSE DATA

Ratio b/a	Reference Location	Antenna Location	Average Relative Response* (dB)
Large	On Surface	1" Below	+ 1.5 (-5 to +7)
Small	12" Above Surface	On Surface	+ 9.0 (-1 to +17)
Small	12" Above Surface	1" Below	+12.5 (-5 to +7)
Small	12" Above Surface	12" Below	+12.0 (-10 to +8)

*Relative to Reference Location

The most salient feature of the data is the increase in average relative response for the on-surface and 1" burial depths. However, an average decrease was noted at a 12" burial depth. The largest increase occurred when the antenna was lowered from 12" above to an on-surface location. It was noted from the input impedance data that the antenna was highly capacitive reactive above the surface, but much less on the surface.

8000:1 Scale Model

Pattern Steerage

An analysis has been completed on the combined use of the Site A NS and EW antennas for radiation pattern steerage. It has been shown that the perpendicular NS and EW antennas at Site A may be combined and phased to project a surface-wave radiation pattern maxima into the NE, SE, NW, and SW quadrants. This capability--in conjunction with the directivity of the antennas where used alone--affords placement of a radiation maxima every 45° over a complete 360° coverage.

Steerage of the surface-wave radiation maxima into the four quadrants can be readily implemented by appropriate combination and phasing of the NS and EW antennas. For example, the configuration shown in Figure 1A places maxima into the NE and SW quadrants. The Figure 1B arrangement forms NW and SE maxima.

A 8000:1 scaled model of the NS and EW antennas, combined and phased as shown in Figure 1A, was constructed and tested on Georgia Tech's 8000:1 scaled simulation of Site A and its environment.

Tests showed that radiation pattern maxima are located toward the NE and SW demonstrating the feasibility of pattern maxima steerage. It was also noted that the basic integrity of the figure-eight pattern is preserved. The nulls lie in the NW and SE quadrants approximately 90° in azimuth from the maxima. Theory indicates that response to the N, E, S, and W should be 3 dB down from the pattern maxima; measured values lie within about 1 dB of this value.

Elevation plan patterns were also obtained and show responses quite similar to previously measured patterns for the individual NS and EW antennas.

A major operational implication is the possible improvement in radiation efficiency to Site C by using the Site A NS/EW antenna combination and phasing shown in Figure 1A. Site C is 55° NE of Site A. Communications with Site C could possibly be enhanced by projecting a pattern maxima into the NE quadrant.

Practical implementation of the NE/SW and NW/SE maxima steerage is relatively simple. 0°/180° phasing networks are already required for driving the individual NS and EW antenna elements. Paralleling of the N and E and S and W elements could be accomplished in the underground operations area where feed lines for all four antenna elements are available.

It is submitted that the above method of obtaining pattern maxima to Site C is superior to the use of an omnidirectional pattern obtained from combining the NS and EW antennas in a 90° phase difference mode. Obtaining and maintaining an exact 90° phase differerence is difficult and requires a quadrature phasing network with additional power loss.

NS/EW Antenna Coupling

The 8000:1 scale model was used to investigate the possible coupling effects between the NS and EW antennas at Site A.

The EW antenna was operated in the active mode; the NS antenna was simulated by a conductor (#28 AWG). Open-circuit NS antenna conditions were simulated by using two conductors--one on each side of the NS axis--with a gap between them. A short-circuited NS antenna was simulated by a single conductor with no gap. It was anticipated that open-circuit and short-circuit coupling effects could differ if any were observed.

Radiation pattern data on the EW antenna indicated discernible, but very small (1 dB), effects on performance. There was a slight indication that the open-circuit effects were less than the short-circuit effects. Intuitively, this should be the case since the short-circuit condition provides a longer antenna element and greater coupling.

Work During Next Interval

During November, work will continue on the 20:1 model investigation, and preliminary work on the final report draft will begin.

Respectfully submitted.

H. H. Jenkins
Project Director

HHJ:gh

Enclosure

Approved:

D. W. Robertson, Chief
Communications Division

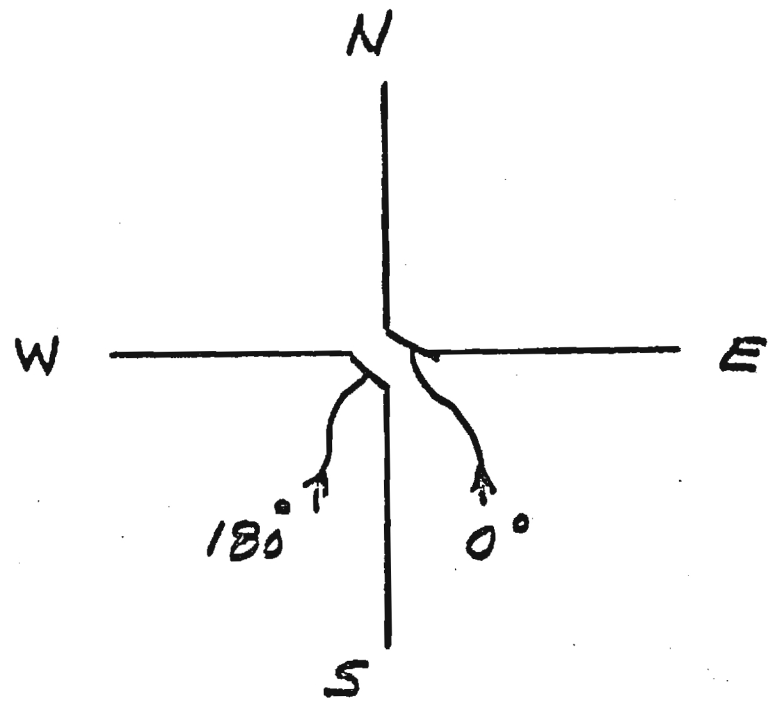

Figure 1A

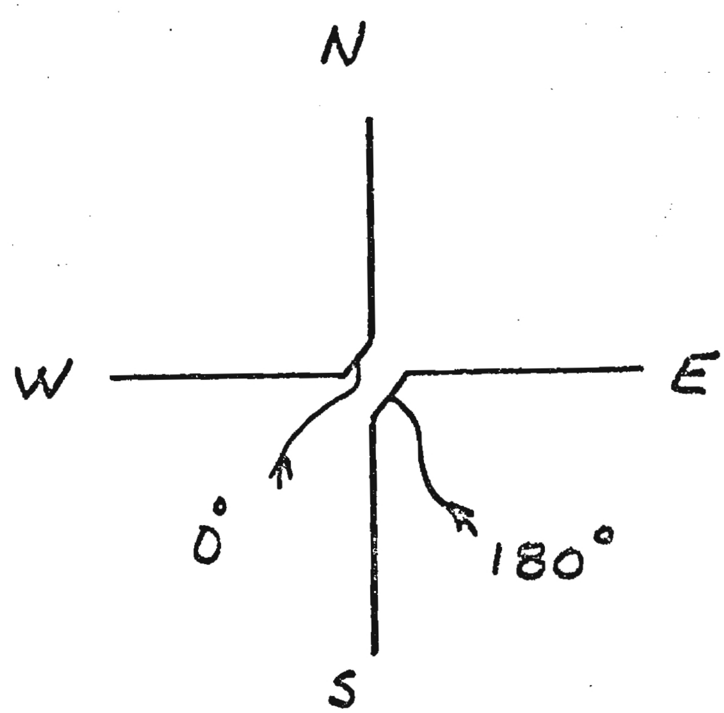

Figure 1B

Figure 1. Depiction of Phasing/Combination For Pattern Maxima Steerage into the NE, SE, NW, and SW Quadrants.

A-1593

ENGINEERING EXPERIMENT STATION

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1 December 1974

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Subject: Monthly Status Report Number 11, Project A-1593, "Buried Dipole Antennas", Contract DAAB07-74-C-0103 1 November to 1 December 1974

Sir:

Field strength calculations have been made for vertically-polarized surface-wave propagation from Site A to Sites B and C for various ground constants and Site A antenna configurations as described below:

1. At Site B for propagation over poor ground (10^{-3} mhos/m) and good ground (10^{-2} mhos/m) based on 100 kW input power into the planned EW dipole antenna.

2. At Sites B and C for the same conditions as (1) above but with the NS/EW dipoles fed for omnidirectional coverage.

3. At Site C for the same condition as (1) above but with the NS/EW dipoles fed for a pattern maxima into the NE quadrant.

An analysis of the estimated path ground conductivities between Site A and Sites B and C was performed using the ground conductivity map for the continental United States as given by Fine [1]. The path from Site A to Site B traverses eight distinct conductivity areas ranging from 2×10^{-3} mhos/m to 15×10^{-3} mhos/m. The average was 10^{-2} mhos/m. The Site A to C path passes through three zones ranging from 1×10^{-3} mhos/m to 4×10^{-3} mhos/m with an average of 2×10^{-3} mhos/m. Therefore, the Site A to B path may be characterized as over good soil ($\sigma = 10^{-2}$ mhos/m; $\varepsilon_r = 15$) and the A to C path as over poor ($\sigma = 10^{-3}$ mhos/m; $\varepsilon_r = 5$) soil.

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[1] H. Fine, "An Effective Ground Conductivity Map for Continental United States", Proc. IRE, Sept. 1954, pp. 1405-1408.

Field strengths were calculated using the method outlined by Terman [2]. For conducting earth and neglecting earth curvative, Terman states that the ground wave field strength, E, is given by

$$E = \frac{(186.3)(A)}{d} \sqrt{GP}, \text{ mv/m}$$

where d = distance in miles,
G = antenna directivity,
P = effective radiated power, from a vertical monopole, kW
and A = a factor which is a function of ground losses.

The factor A is a complicated function of path conductivity and dielectric constant, frequency, and distance from the transmitter in wavelengths. Terman presents plots of A as a function of two auxiliary variables, the numerical distance and phase constant. Calculations of these auxiliary parameters were made and corresponding A factors obtained.

The resultant expressions for field strength were obtained as listed below:

<u>Site B: $\sigma = 10^{-2}$ mhos/m</u>

$$E = 0.154 \sqrt{GP}, \text{ mv/m}$$

<u>Site B: $\sigma = 10^{-3}$ mhos/m</u>

$$E = 0.045 \sqrt{GP}, \text{ mv/m}$$

<u>Site C: $\sigma = 10^{-2}$ mhos/m</u>

$$E = 0.254 \sqrt{GP}, \text{ mv/m}$$

<u>Site C: $\sigma = 10^{-3}$ mhos/m</u>

$$E = 0.113 \sqrt{GP}, \text{ mv/m}$$

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[2] F. E. Terman, "<u>Electronic and Radio Engineering</u>", Fourth Edition McGraw Hill, New York, N. Y., 1955.

For transmission to Site B, the EW dipole would be used with a nominal directivity of 2.14 dB or G = 1.64. Modeling results indicate that the planned EW antenna should have approximately the same efficiency as the present NS antenna. Therefore, we will use an efficiency of 0.15% for westward (282°) radiation. This provides a P value of 0.15 kW effective radiated power. Using GP = 0.246, the calculated signal levels for Site B from the EW antenna are:

$$E = 0.076 \text{ mv/m}, \ \sigma = 10^{-2} \text{ mhos/m},$$

and $$E = 0.022 \text{ mv/m}, \ \sigma = 10^{-3} \text{ mhos/m}.$$

When the omnidirectional radiation mode is used, it is expected that the effective radiated power will be reduced due to additional power loss introduced by the 90° phasing and combining networks between the transmitter and the antenna. As an approximation, it is estimated that as much as 2 dB loss may be introduced. This additional loss negates the directivity factor; therefore, in the above expressions, G = 1 and P = 0.15 kW. The resultant signal levels are as listed below:

Site	σ (mhos/m)	E (mv/m)
B	10^{-2}	0.059
B	10^{-3}	0.017
C	10^{-2}	0.098
C	10^{-3}	0.044

When the NS/EW antennas are combined to produce a NE quadrant maxima, the directivity to Site C is about 1.64 and, with P = 0.15 kW, the GP factor is 0.246 kW leading to:

$$E = 0.126 \text{ mv/m}, \ \sigma = 10^{-2} \text{ mhos/m},$$

and $$E = 0.056 \text{ mv/m}, \ \sigma = 10^{-3} \text{ mhos/m}.$$

Table I presents a summary of the field strength calculations.

It is estimated that at LF, the effects of earth curvature are negligible up to about 600 miles and are not serious until the distance exceeds about twice this value. Therefore, the values shown in Table I should be representative for both Site B and C levels.

Antenna	Site	σ (mhos/m)	E (mv/m)
EW	B	10^{-2}	0.076
EW	B	10^{-3}	0.022
NS/EW OMNI	B	10^{-2}	0.059
NS/EW OMNI	B	10^{-3}	0.017
NS/EW OMNI	C	10^{-2}	0.098
NS/EW OMNI	C	10^{-3}	0.044
NS/EW NE Quadrant	C	10^{-2}	0.126
NS/EW NE Quadrant	C	10^{-3}	0.056

TABLE I. CALCULATED FIELD STRENGTH VALUES

Work has begun on preparation of the draft for the Final Technical Report.

Work During Next Interval

During December, the Final Technical Report draft will be completed.

Respectfully submitted,

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Project Director

HHJ:gh

Approved:

D. W. Robertson, Chief
Communications Division